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Evaluation of GAC (Granular Activated Carbon) Performance and On-Site Reactivation at the Manchester, NH. Water Treatment Plant

Manchester Water Works, NH

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D. Paris,[1] R. Beaurivage, P.E.,[1] D. Kittredge, P.E.,[1] and B. Lykins,[2]

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Manchester, NH
[2]USEPA, Cincinnati, OH 45268

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16. ABSTRACT

The performance and cost of reactivating granular activated carbon at a fluidized bed reactivation system was studied. The feasibility of on-site reactivation,as well as regionalized reactivation, was demonstrated.

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EVALUATION OF GAC PERFORMANCE AND ON-SITE REACTIVATION AT THE MANCHESTER, NH WATER TREATMENT PLANT

EPA/600/D-86/178

David Paris
Robert Beaurivage, P.E.
David Kittredge, P.E.
Benjamin Lykins

Manchester Water Works
Manchester, NH

In the late 1960's, the Manchester Water Works (MWW) was facing a situation of decreasing quality and increasing demand for water. To augment the current supply (Lake Massabesic), preliminary proposals called for the Merrimack River to be used. Dealing with the taste and odor problems emanating from the lake as well as the purification of a river supply indicated the need for a water treatment plant. As a result of these concerns, a 40 MGD facility utilizing conventional treatment with series sand and granular activated carbon (GAC) filtration was constructed and put on line in the fall of 1974 (figure 1). The plant services over 100,000 population and has been cited for numerous awards of engineering excellence. The operation and maintenance of the water treatment plant is the responsibility of ten operators, a biologist and a plant manager/chemist. The water treatment plant and forestry divisions of the MWW water supply are under the auspices of a professional civil engineer.

As early as 1976, the problem of what to do with in excess of 500 tons of spent GAC was confronting the MWW. Disposal and replacement versus on- or off-site reactivation were the plausible alternatives. A study of the costs involved with each dictated on-site reactivation as being the most cost effective alternative. Concurrently, the United States Environmental Protection Agency (USEPA) was interested in evaluating the use of GAC and on-site reactivation by a typical U.S. water utility. Conclusions regarding economics of operation and reactivation effectiveness were the objectives to be realized.

To this end, the MWW and USEPA became partners in a cooperative agreement to build and study a full-scale fluidized bed reactivation system at the Manchester Water Treatment Plant. This was the first such installation in the United States. The desire to provide a three-month turnaround cycle on 500 tons of GAC dictated that the capacity of the reactivation system be six tons per day. In order to accommodate a system of this size, a three-story (35' x 40') addition was erected to the water treatment plant filter room in late 1978. Within this building, a reactivation system designed by the Westvaco Corp. of Charleston, SC was installed.

The reactivation system is highlighted by the use of a two-stage fluidized bed process (figure 2). The first stage of this process is a fluidized drying bed receiving dewatered GAC from a dewatering screw conveyor. The GAC is dried at 300^{o}F and then fed to the main reactivation area. This reactivation zone has an area of approximately 7 feet^{2}. At 500 pounds per hour, the bed exchange is approximately 30 minutes. During this stage, the GAC is in a fluidized state with high temperature gases consisting of combusted fuel oil and steam providing a fluidizing gas upflow velocity of 1.4 feet per second. The combination of elevated temperatures (1,650^{o}F) and the excellent energy

...ge properties of the fluidized bed purge the GAC of adsorbed ...nic impurities. The desorbed materials are transported by the ... flow to the enriched oxygen atmosphere of the incineration zone ...here they are oxidized. Energy released in the incinerator radiates back on the main bed and serves as energy input to the dryer bed. The base carbon integrity is retained throughout via the lack of excess oxygen in the main reactivation bed. In all cases outside of the dewatering screw conveyor, GAC transport requirements are met through the use of hydraulic eductors. Velocities of two to five feet per second and the use of wide sweeping bends minimize GAC losses due to abrasion during transport. Bulk GAC storage tanks of 1,200 feet^3 each provide space in the reactivation room for a 48-hour inventory of spent and reactivated GAC.

After trial and subsequent abandonment of a prototype, semiautomatic carbon handling system retrofitted to our backwash carriages, a simple, manually operated eduction system was settled upon for our GAC filter transport requirements. This very simple arrangement (figure 3) was settled upon as the least expensive and most reliable method for moving GAC. The major advantages to the manual system were low maintenance and the capability to empty the GAC filter bed completely. The semiautomatic system proved inadequate in these areas.

Our initial experience with the reactivation system clearly demonstrated its high level of complexity and maintenance requirements. As the unit was operated and maintained by the same water treatment plant staff who operate and maintain the water treatment plant, requirements for training and increased manpower quickly became evident. The Westvaco Corp. provided valuable assistance with the former while the latter was satisfied via the addition of two full-time personnel and the dedication of a third to strictly reactivator duties.

The reactivation system experienced some equipment failures and design shortcomings which complicated the initial attempts at operation. Specifically, we found problems with the reactivator system in the following areas:

- Rapid corrosion of 304 stainless steel in contact with spent GAC.
- Spalling and partial failure of the refractory lining.
- Instrumentation failures precipitated by severe environmental conditions of temperature and vibration.
- Inadequate steam supply.
- Scrubber and subsequent blower failures precipitated by corrosive attack and particulate deposits.

Field engineering and supplemental backup equipment installations were necessary to correct these problems. With adequate revisions, the reliability of the furnace was raised from an initial operating factor of 30% to a more creditable 75% by project completion. The installation of redundant or "standby" equipment was a major factor in raising the operating factor.

A summary of the cost data associated with operation is seen in table 1. The information presented reflects actual expense. The

final cost of 21 cents per pound includes all expenses for reactivation. Notably, makeup carbon due to volumetric losses constitutes nearly one-third of this cost.

The remaining question in all of this concerns the effectiveness of the reactivated GAC. It is evident that the extent of reactivation and reusability of the GAC is the primary enabling factor indicating whether fluidized bed or other reactivation systems are an economically sound investment. To answer this question, a full-scale aqueous research program was undertaken. Our research was tailored to meeting the following criteria:

1. That it be a full-scale evaluation, utilizing a 10 MGD filter bed.
2. That it provide a side by side comparison of GAC's which differ only in number of times reactivated.
3. That the adsorbates monitored should be of relevance to the interests of the water industry.
4. That the side by side system of comparison be initially performed for virgin and once reactivated GAC and, subsequently, repeated for multiple activated cycles, i.e., once reactivated versus twice reactivated for run 2 and twice reactivated versus three times reactivated for run 3.

The first criteria mentioned above was met through the conversion of one 10 MGD GAC filter bed to a "test filter". The MWW utilizes the multicellular "Hardinge" type automatic backwash filter. The multicellular, compartmented design of these filters, facilitated the direct comparison of differing media types. In addition to the ability to load the filter discriminately with differing medias, the effluents from the different medias do not mix laterally as the filter effluents follow a laminar upflow pattern. This allows the discriminate aqueous sampling of each filter section effluent without fear of mixing from any other section. Backwashing rates and frequencies as well as adsorbate loadings and service times remain constant for all cells in a given filter bed. Empty bed contact time (EBCT) ranges from 7.6 minutes at maximum loading to a more characteristic EBCT in excess of 20 minutes (average). The test filter configuration and sampling system is shown in figure 4.

This experimental design allowed us to fulfill criterions one and two. By loading the test filter with two GAC medias differing only in reactivation cycle, we achieved a plant scale side by side comparison. This side by side comparison was carried out through three full monitoring cycles as outlined below:

Monitoring Run	GAC Comparison Undertaken
Run 1	Virgin Vs One Reactivation
Run 2	One Reactivation Vs Two Reactivations
Run 3	Two Reactivations Vs Three Reactivations

The GAC monitoring program consisted of measurements to determine adsorptive capacity for total organic carbon (TOC), trihalomethanes

(THM's) and trihalomethane formation potential (THMFP). THMFP was divided into four categories of temperature and contact time combinations. Supplemental analyses for bacteriological, ph, turbidity and color removal were run. In addition, we periodically performed similar analyses on grab samples from our supply and water treatment process. These so-called "plan profile" analyses were extremely useful in providing a frame of reference from which to evaluate the GAC's performance (table 2).

In an attempt to gain as broad and realistic an understanding of the reactivation system as possible, consultants were hired for exhaust stack and laboratory GAC characterizations. A summary of this data is presented in tables 3 and 4.

Our attempts at GAC loss measurements were many and widely varied. Measuring the mass of GAC loss via a mass balance analysis was used initially; however, we found that this method for quantifying losses was not adequate for our needs. As a measure of GAC loss, the mass balance analysis does not address the general concern of the waterworks industry for completely refilling the reactivated filter bed. Fluctuations in mean particle size and apparent density following reactivation are likely responsible for bulk density changes of the GAC in the filter bed. This, in turn, affects the volume occupied (table 4). The development of an accurate and repeatable method for quantifying volumetric losses was a prime objective of our research. Accurate determination of the GAC level in the spent and reactivated storage tanks was an absolute necessity for the volumetric determination. We found this to be a major obstacle in obtaining precise and repetitious data due to the turbid conditions and indefinite "feel" of the carbon-water interface. The loss figures are tabulated in figure 6. They indicate a downward trend with progressive reactivation cycle and show a range of 14% to 9% for overall losses encountered when measured from filter to filter. We saw loss values due to transport activities alone in the 2% to 5% range. While we found that the total volumetric losses encountered in GAC reactivation are somewhat difficult to quantify precisely, we feel confident in the ranges and trends presented. A trial reactivation program carried out with bituminous GAC from two neighboring utilities indicated filter to filter losses averaging 13% (table 5). This corrobation of first reactivation volumetric loss numbers found for Manchester was gratifying.

A comparison of GAC capacities for THM, TOC, and THMFP (seven day, 28.5°C) is seen in figures 7 - 12. This data clearly shows reactivated adsorption capacity exceeding levels measured for virgin carbon in all cases. In this comparison, it is important to note that while the virgin carbon purchased in 1979 was of identical specification as that purchased in 1974 and reactivated for the first time in 1979, it is a different batch. Also, there is some inherent error in comparing run 1 to run 2 and/or 3 in that loading conditions, contact time and water temperatures were different run to run. However, even with these considerations in mind, it is difficult not to see the similarity between the cumulative removal capacity from run to run. The only cumulative removal values which substantially deviate (lower) are those of the virgin material. The fact that the performance of the virgin material improves to a level approximately the same as other reactivated values following reactivation is further evidence of the reactivator's effectiveness. It is this pattern of complete recovery following reactivation which provides the practical justification for the use of reactivated carbon by a water utility.

BET, iodine number and decolorizing index analyses demonstrate the same pattern of increasing activity with repeated reactivation (table 4). A decrease in mean particle diameter and an increase in the ash percent of the GAC are also notable. Also, one other notable consequence of reactivation was the decrease in mean particle diameter. The inherent defining characteristics of the fluid bed system produce a notable shift in the particle size distribution of the GAC. In practice, this means higher filterability of the reactivated media and along with this increase in filterability, increased head loss characteristics.

The final area of our research entailed a program of regionalized reactivations. This program involved reactivation of approximately 20 tons of GAC from each of the three participating New England utilities; two utilities with bituminous GAC and a third with a lignite based GAC. By gaining data on cost effectiveness of this program, it was hoped that some conclusions could be reached on the efficacy of a regional approach to GAC reactivation.

We found that the reactivation of lignite based GAC produced approximately twice the volumetric losses as with bituminous material. As mentioned previously, the volumetric losses encountered with the bituminous based GAC's were directly in line with the 14% values obtained in Manchester. Conclusions reached on reactivation effectiveness of these three batches was limited to laboratory analyses (table 5). Although a certain amount of on-site organics removal information was gathered at each utility, it is difficult to ascribe any significance to it without having a side by side basis for comparison.

We feel that this experiment demonstrated the feasibility of a regional approach to municipal water supply GAC activation. The cost effectiveness of this program is especially apparent for those smaller utilities utilizing bituminous carbon within approximately 100 miles of Manchester. The high level of reactivation capacity and comparatively low cost (approximately 50% of the cost for virgin GAC in the northeast) makes regional reactivation a viable and cost effective alternative for many utilities.

The MWW and USEPA have both benefited directly from this endeavor. From Manchester's viewpoint, the capability to monitor and maintain full adsorbancy in its GAC filter beds has been attained. The USEPA has been able to demonstrate the feasibility of on-site reactivation and to develop a case for regional GAC reactivation. Our research indicated that fluidized bed reactivation will restore spent GAC to an adsorbancy level, comparing favorably with virgin material. The overall cost to reactivate GAC was 21 cents per pound which is about one-quarter the delivered price of virgin GAC. The cost effectiveness of this process is thereby quite evident. It is our hope that the results of this program will help guide others in the water supply industry with their future plans concerning GAC use and reactivation.

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SITE PLAN
MANCHESTER, NH WATER TREATMENT PLANT

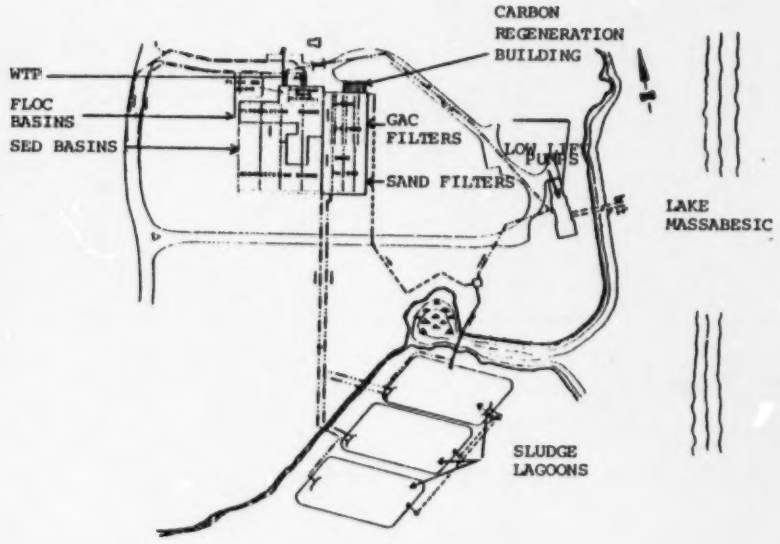


Figure 1

Process Flow for Activated Carbon Regeneration System at Manchester

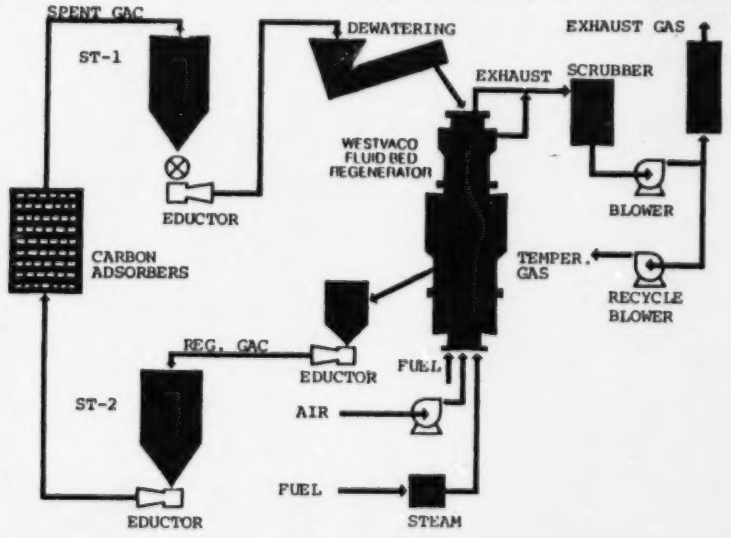


Figure 2

MANUAL EDUCTION SYSTEM

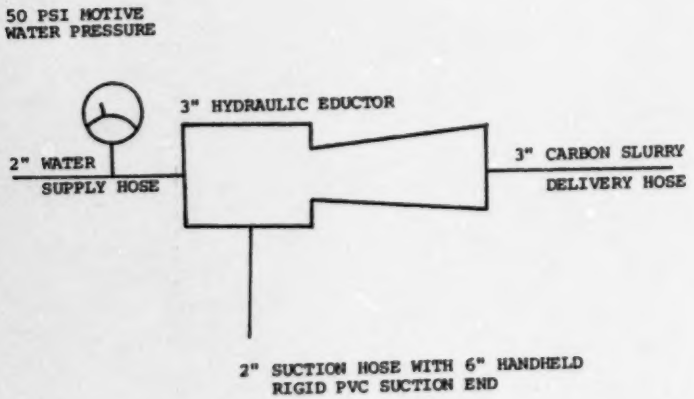


Figure 3

WTP SAMPLING AND CHEMICAL FEED SCHEMATIC

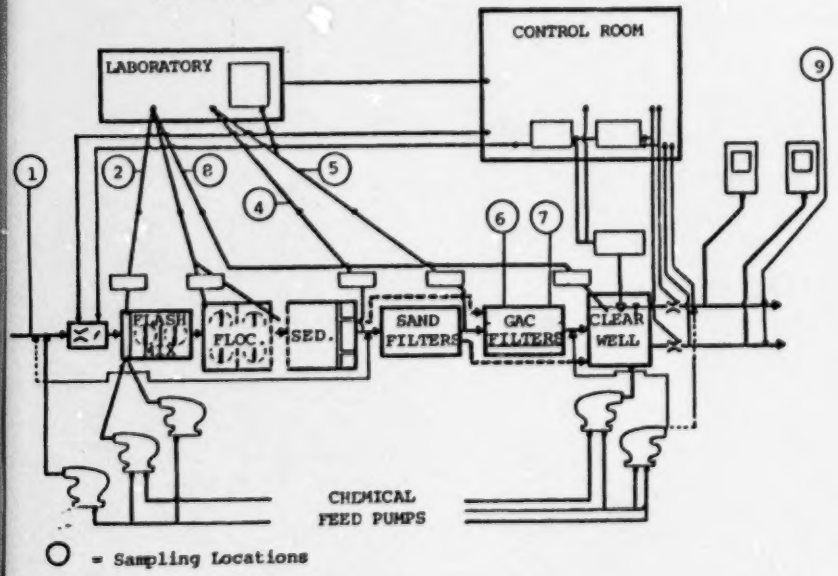


Figure 4

MWW GAC FILTER CONFIGURATION

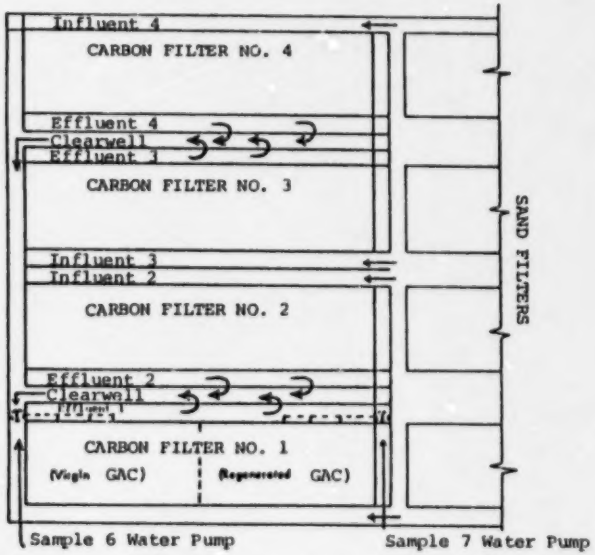


Figure 5

SUMMARY OF MWW GAC
VOLUMETRIC LOSSES

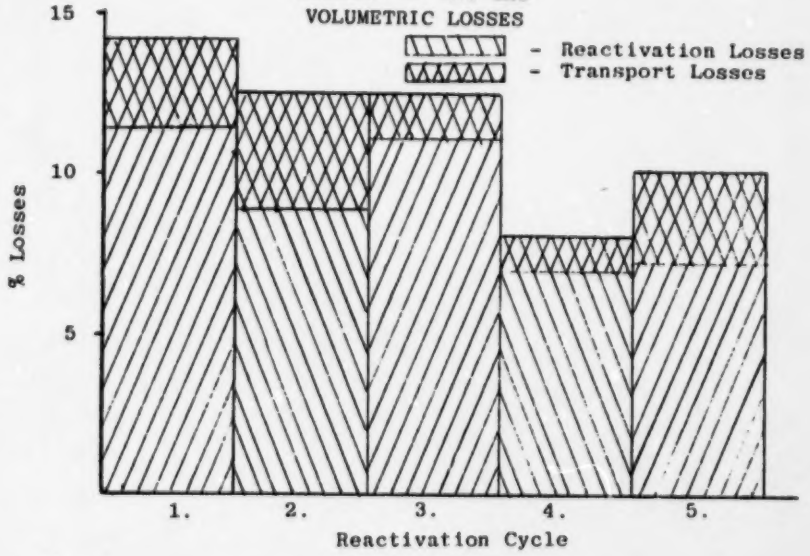


Figure 6
Note: Reactivation loss plus transport loss approximate overall filter to filter loss.

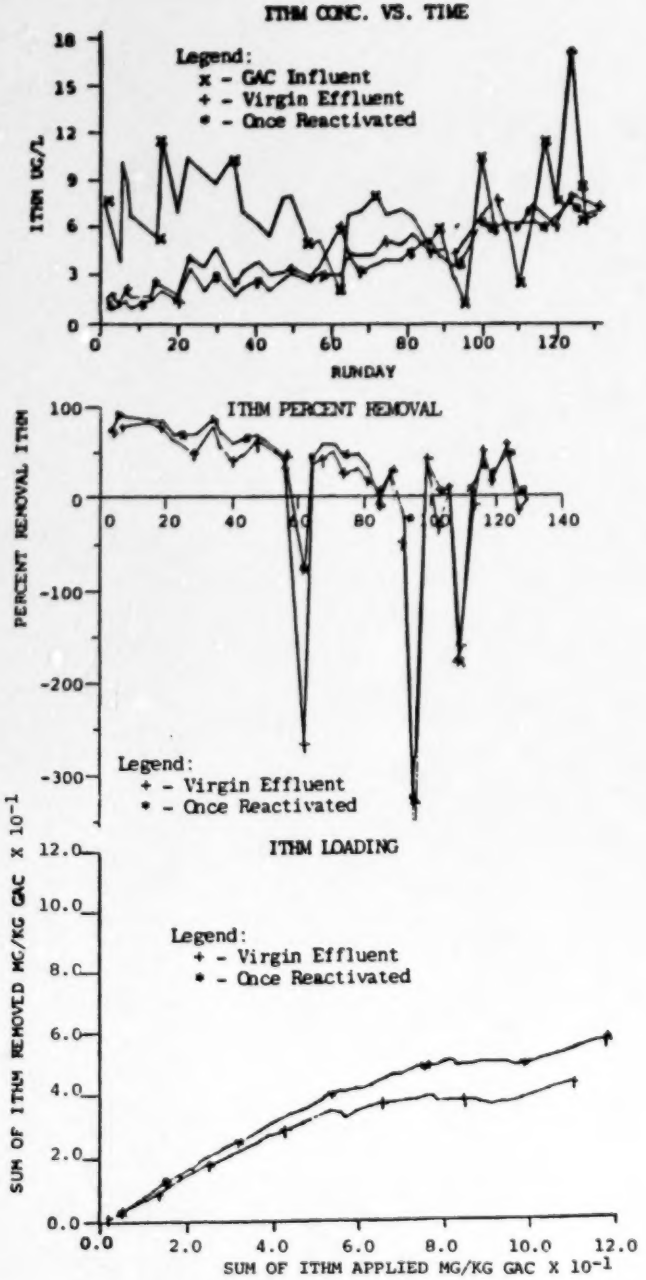


Figure 7

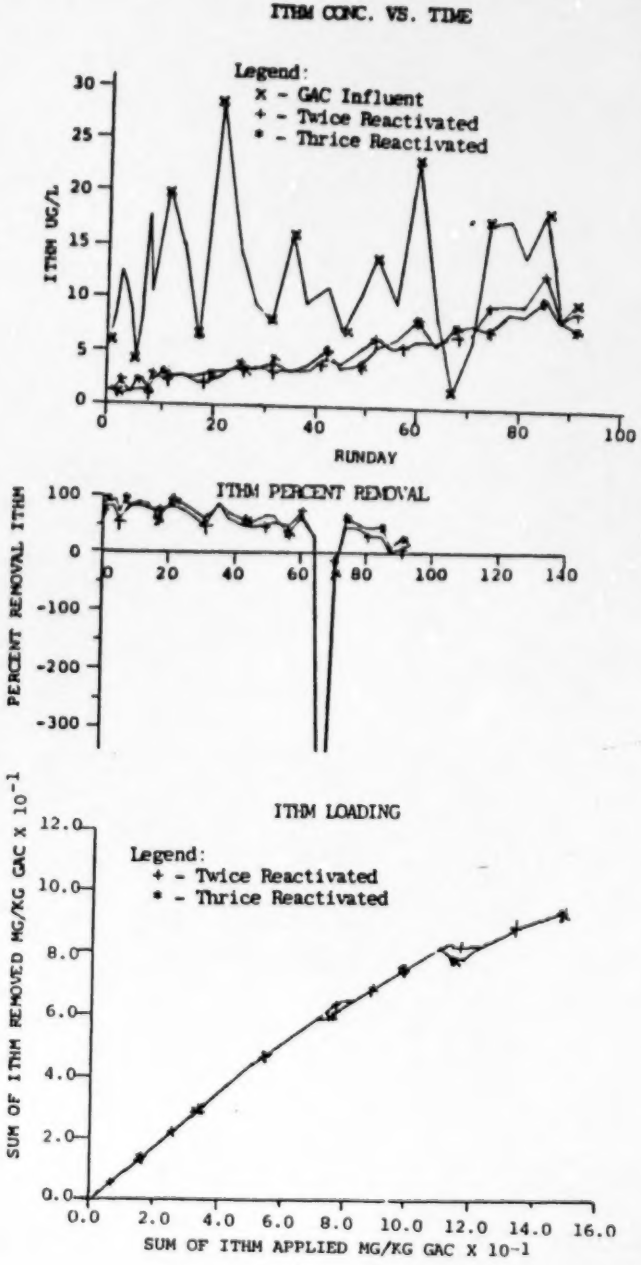


Figure 8

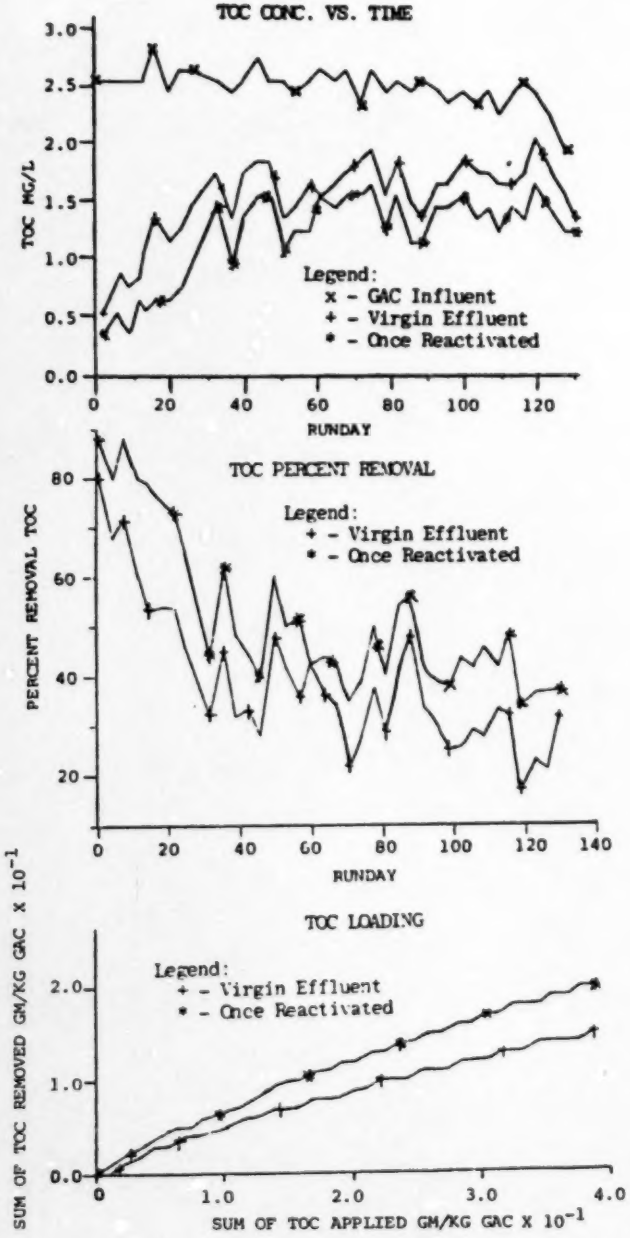


Figure 9

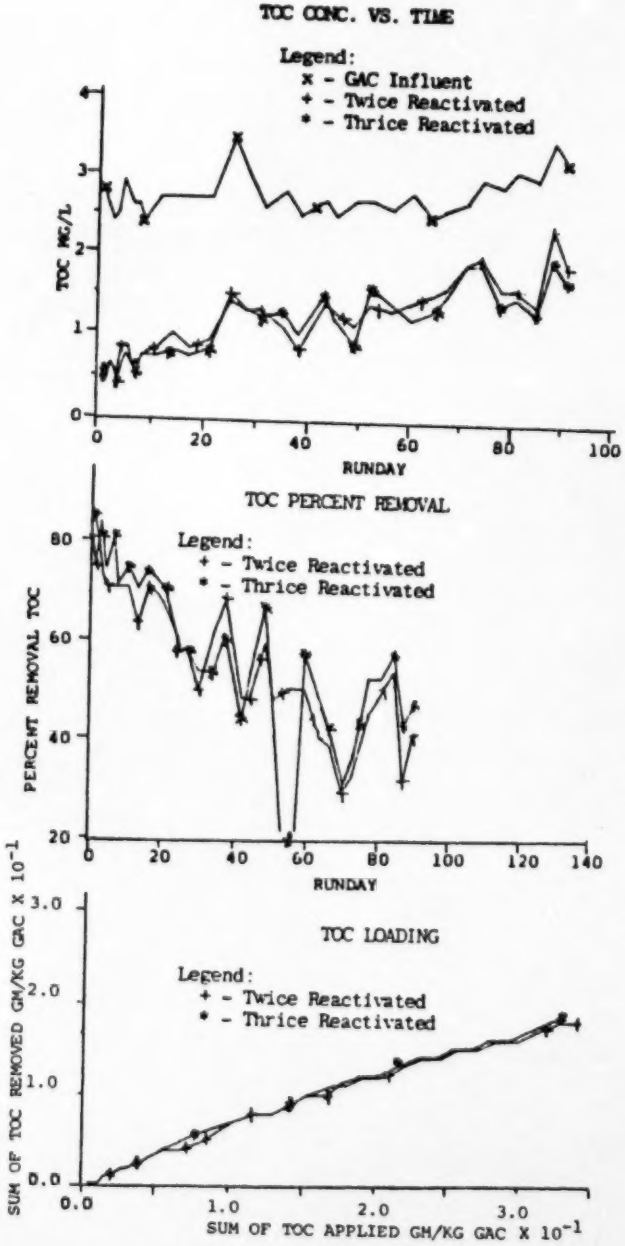
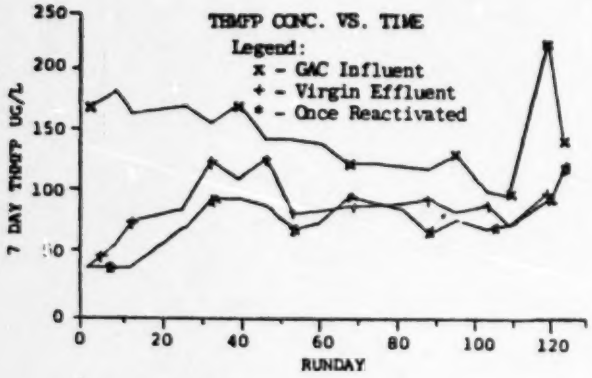
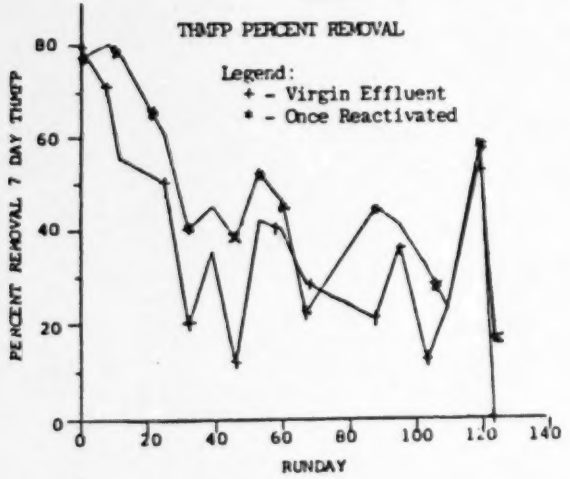


Figure 10





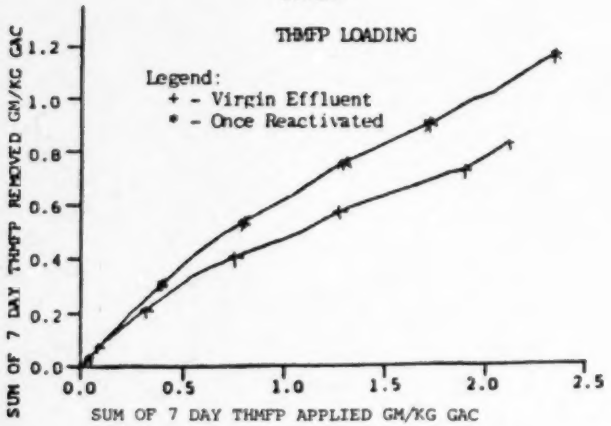
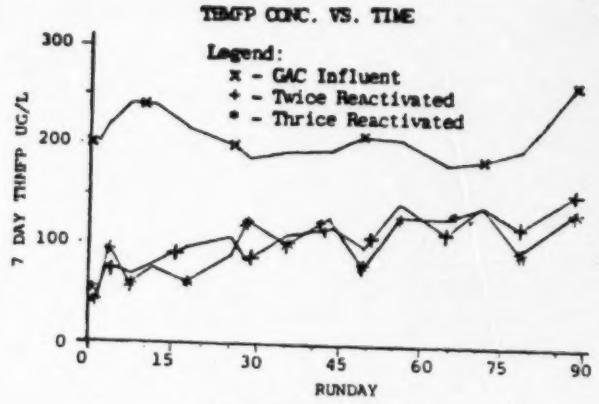
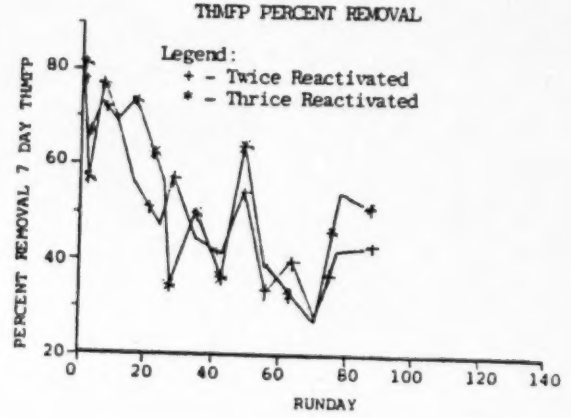

THMFP LOADING
Legend:
+ - Virgin Effluent
* - Once Reactivated
SUM OF 7 DAY THMFP REMOVED GM/KG GAC
SUM OF 7 DAY THMFP APPLIED GM/KG GAC

Figure 11





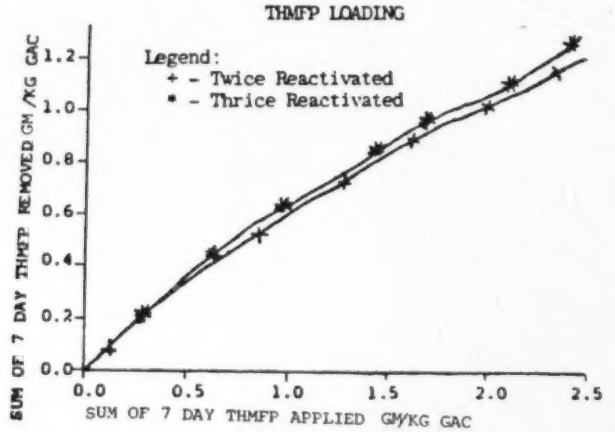

THMFP LOADING
Legend:
+ - Twice Reactivated
* - Thrice Reactivated
SUM OF 7 DAY THMFP REMOVED GM/KG GAC
SUM OF 7 DAY THMFP APPLIED GM/KG GAC

Figure 12

TABLE 1
MANCHESTER WATER WORKS
ACTUAL REGENERATION COSTS
JUNE 1980 THROUGH MARCH 1981
(BASED ON REACTIVATION OF 1,857,176 LBS. OF GAC)

	Cost Item	Cost Per Pound
A)	Makeup Carbon	7.07¢
B)	Labor for Reactivation	1.94¢
C)	Labor for Transport	0.28¢
D)	Labor for Lab	0.05¢
E)	Labor Administration	1.32¢
F)	Parts and Service Calls	2.67¢
G)	Fuel Oil	2.23¢
H)	Power	0.50¢
I)	Water	0.74¢
J)	Lab Supplies	0.05¢
K)	Depreciation	1.39¢
L)	Overhead*	2.76¢
	Total Cost	21.00¢/Lb.

*Based on a factor of 77% above labor costs that includes holidays, vacation, sick leave and fringe benefits. Actual total MWW overhead is 305% above labor costs.

See Appendix I for further detail.

AQUEOUS MONITORING PROGRAM

SITE NO.	LOCATION	ITHM/WK	THMP/WK 3A,3M	THMP/WK 7A,7M	TOC/WK	TURBIDITY PH/WK	TOTAL COLIFORM & STD. PLATE COUNT/WK
1.	Raw	1	1	1	2	7	1
2.	Pre Flash Mix	1	1	1	2	7	1
4.	Post Sedimentation	1	1	1	2	7	1
5.	Post Sand Filtration	2	2	1	3	7	1
6.*	Post GAC	2	2	1	3	3	1
7.*	Post GAC	2	2	1	3	3	1
8.	Combined Plant Post GAC	1	1	1	2	7	1
9.	Typical Mid and End Distribution Sites	2	1	1	2	2	2

*Site 6 Run 1 (R1) Virgin — Run (R2) One Reactivation — Run 3 (R3) Two Reactivations

*Site 7 One Reactivation — Two Reactivations — Three Reactivation

ITHM - Instantaneous Trihalomethane Concentration
TOC - Total Organic Carbon Concentration
THMFP - Trihalomethane Formation Potential Concentration
3A - THMFP for 3 days Cl_2 contact at ambient temperature conditions
7A - THMFP for 7 days Cl_2 contact at ambient temperature conditions
3M - THMFP for 3 days Cl_2 contact at 28.50°C (maximum system temperature)
7M - THMFP for 7 days Cl_2 contact at 28.50°C (maximum system temperature)

Table 2

FLUIDIZED BED EXHAUST STACK ANALYSIS

Flue Gas Characteristics	Avg. of 3 Runs
Velocity (FPM)	1163.517
Flow (ACFM)	1218.425
Flow (DSCFM)	406.142
Excess Air (%)	46.167
Stack Temperature (F)	142.000
Moisture (%)	18.833
Oxygen (%)	6.800
Carbon Dioxide (%)	11.333
Sampling Conditions	
Isokinetics (%)	96.888
Measured Particulate Emissions	
(Grains/USCF)	0.0396
(mg/dscf)	2.5736

Data supplied by Environmental Research & Technology, Inc.

Table 3

PHYSICAL GAC CHARACTERISTICS [1, 2]

PROPERTY	VIRGIN WVW	1 REACT.	2 REACTS.	3 REACTS.
BET M^2/g	789	806	814	751
IODINE mg/g	795	898	1,045	1,073
MOD PHENOL VALUE (AWWA) g/ℓ	2.48	2.58	2.37	2.22
MOLASSES DECOLORIZING INDEX - DI/g	3.2	4.3	4.6	5.3
VOLATILE MATTER PERCENT	6.72	6.55	6.45	6.1
ASH PERCENT	5.42	6.73	6.75	7.25
APPARENT DENSITY g/mℓ (lb/ft^3)	.614 (38.3)	.586 (36.6)	.582 (36.3)	.558 (34.8)
MEAN PARTICLE DIAMETER mm	1.42	1.37	1.38	1.24
ABRASION NUMBER PERCENT MEAN	77.7	79.5	87.7	87.6

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1. All data shown compiled from analyses performed by or under the auspices of Dr. Stan Smith, Doraville, GA.
2. All samples represent composited GAC samples taken from the test filter bed after backwashing prior to being put in service.
3. GAC evaluated is Westvaco 8 x 30 WVW

Table 4

TABLE 5

REGIONAL REGENERATION STATISTICS

UTILITY	GAC	APPARENT DENSITY (LB/FT^3)		MEAN PARTICLE DIAMETER (mm)		IODINE NUMBER (mg/g)		TOTAL LOSSES BY VOLUME
		SPENT	REACTIVATED	SPENT	REACTIVATED	SPENT	REACTIVATED	
CONNECTICUT WATER CO.	Carborendum Lignite 8 x 30	28.5	24.7	1.57	1.43	380	660	23.5%
DANVERS, MA WATER WORKS	Calgon Bituminous 8 x 30	37.0	33.7	1.53	1.16	664	985	11.5%
LOWELL, MA WATER WORKS	Westvaco Bituminous 8 x 30	35.3	31.7	1.43	1.16	640	1,024	15.3%

APPENDIX I

EXPLANATION OF REACTIVATION COST ITEMS

A) Makeup Carbon. Based on an average total carbon loss of 11.5% experienced through five cycles of reactivation at a delivered cost to Manchester of 61.5 cents per pound.

B) Labor for Reactivation Operation and Maintenance. Based on a staff of twelve water treatment plant operators at an average wage of $6.52 per hour. Each operator would spend an average of 9.4 hours of a 42 hour work week operating and maintaining the GAC reactivator.

C) Labor for Transport Operation and Maintenance. Based on a staff of twelve water treatment plant operators at an average wage of $7.32 per hour. Each operator would spend an average of 1.6 hours of a 42 hour work week transporting GAC to and from the filter beds to the reactivator.

D) Labor for Laboratory Analysis to monitor quality control of the reactivat_on process. Based on a staff of one laboratory technician at a wage of $7.56 per hour. This technician would spend an average of 4 hours of a 40 hour work week performing analyses.

E) Labor for Administration. Based on a staff of two engineers, chemist, secretary, purchasing agent and accountant.

F) Parts and Service Calls. Based on an average cost of $13.89 per hour of reactivator operation for new parts, repair shop charges, and outside service calls. This does not include Water Works labor.

G) Fuel Oil. Based on an average cost of $1.035 per gallon of fuel oil and consumption of 11.2 gallons per hour of regeneration (or, 2,994 BTU per pound of carbon.)

H) Power. Based on an average cost of 5.32 cents per KWH and a consumption of 48.6 KW per hour of operation (or, 0.093 KWH per pound of carbon.)

I) Water. Based on a water production cost of $32.13 per 1,000 gallons and a consumption of 11,792 gallons per hour of reactivator operation (or, 22.7 gallons per pound of carbon.)

J) Lab Supplies to perform reactivation process quality control analysis. Based on an average of $100. per month for supplies.

K) Depreciation. Based on capital construction costs of $258,345. for the building depreciated over 35 years and $528,000 for equipment depreciated over a period of 15 years at a 75 percent operating factor.

L) Overhead. Based on a MWW overhead factor of 77 percent above labor costs that includes holidays, vacation, sick leave and fringe benefits. Actual total MWW overhead is 305% above labor costs.